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ABSTRACT

The degree to which human intelligence can be improved by psychological and educational means will depend largely upon the level of analysis accepted as representing intelligence. Training and structured learning can enhance achievement in the form of knowledge and skills. Traditional Intelligence Tests (IQ) are fairly broad samples of achievement, yet persons differ widely in achievement when their opportunity and motivation for achievement are similar. Such variation implies that something more than the quantity and quality of experiential input is involved in human variation in ability. Future attempts to improve children's intelligence will probably be directed at a different class of psychological variables than those now thought of as intellectual achievement. Current information processing models of intelligence view a number of elementary cognitive processes (ECP) and metaprocesses (MP) as the basic underpinning's of intellectual achievement. The various ECP's are correlated through their sharing of common physiological processes. Different sets of elementary processes can be utilized by a given meta process. Both processes and metaprocesses enter into performance on complex psychometric tests. Most of the present attempts at training up intelligence have their greatest observable effects at the level of specific psychometric tests. Academically gifted children differ from their more average age-mates not only at the level of academic knowledge and high-level scholastic skills, but in speed and efficiency at the level of the most elementary cognitive processes. At the practical level, where financial and educational resources are limited, selection rather than training will more quickly and efficiently increase the amount of manifest talent from a population. (KGB)

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The Plasticity of "Intelligence" at Different Levels of Analysis

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My present position regarding the degree to which human intelligence can be improved by psychological and educational means is that the answer will depend largely upon the level of analysis accepted as representing "intelligence."

My study of the research literature concerning experimental attempts to raise the intelligence of children leads me to several conclusions in which I have varying degrees of confidence. First, I feel most confident that there is no compelling or convincing evidence, as yet, that training techniques have any effect on intelligence conceived of as Spearman's g in the broadest sense. The small and usually transient effects on g that have been claimed for some studies can be explained more parsimoniously in terms of certain psychometric artifacts. It has been possible, certainly, to demonstrate gains on specific tests, including certain standard IQ tests. What has not been demonstrated, however, is that the individuals in the treated groups whose IQs have been raised relative to an untreated control group will show comparable gains on other, superficially dissimilar, g-loaded tasks or that they will perform like untreated persons of the same IQ in those "real life" pursuits which make intellectual demands. Virtually all of the evidence I have seen, from numerous compensatory education programs and from small but intensive studies such as the Milwaukee Study of Heber and Garber (1979) or the Abecedarian Project in North Carolina

(Ramey, Collier, Sparling, Loda, Campbell, Ingram, & Finkelstein, 1976), is consistent with the hypothesis that it is the specificity, and possibly certain small group factors, of the IQ tests, which have been trained up, rather than the g factor itself. Such results are discouraging to people interested in raising IQ, as it is the g factor which represents the "active ingredient" of IQ in terms of its broad predictive validity and the breadth of transfer of the effects of training.

Training and structured learning can undoubtedly enhance achievement in the form of knowledge and skills. That is mainly what education is about. Effective and efficient performance in virtually all tasks of at least moderate complexity depends upon a store of knowledge or skills gained by learning, practice, and experience. And all biologically normal persons are able to achieve through learning, practice, and experience. Traditional IQ tests are fairly broad samples of achievement. The problem is that persons differ widely in achievement even when their opportunity and motivation for achievement are highly similar. Such variation implies that something more than the quantity and quality of experiential inputs is involved in human variation in ability. The persistence of this great variation in the face of our best attempts to equalize opportunity and maximize motivation for learning and intellectual development is one of the factors that makes the study of human intelligence so fascinating, problematic, and controversial. The clear perception that something more than inequalities of experiential input is involved in inequalities of achievement, a perception unchallenged for centuries by all but a few psychologists, is largely the basis for the notion of mental ability,

or aptitude, that is independent of achievement, and in some sense more basic. Hence, educators and policy makers in recent years have shown as much or even more concern with improving children's intelligence as with improving education in the traditional sense. And yet, while there seems little doubt that we can improve education and the general level of achievement in the traditional school subjects, there is considerable doubt, at present, that we are able to improve people's intelligence in the sense of aptitude, independent of achievement.

Future attempts to improve children's intelligence, not with guaranteed results, but as an experiment, will probably be directed at a different class of psychological variables than those we now generally think of as intellectual achievement. Current information processing models of intelligence view a number of elementary cognitive processes (ECP) and metaprocesses (MP) as the basic underpinnings of intellectual achievement. One central question in this line of research concerns the trainability of the ECPs and MPs and the plasticity of individual differences therein.

The relationship of the ECPs and MPs to the domain of psychometric intelligence can be represented by the simple hierarchical model shown in Figure 1.

Insert Figure 1 about here

The horizontal dashed line in Figure 1 separates the behaviorally or psychologically measurable variables (above the line) from those that are measurable only physiologically, such as evoked brain potentials, or from those that are less directly measurable, by means of inferred

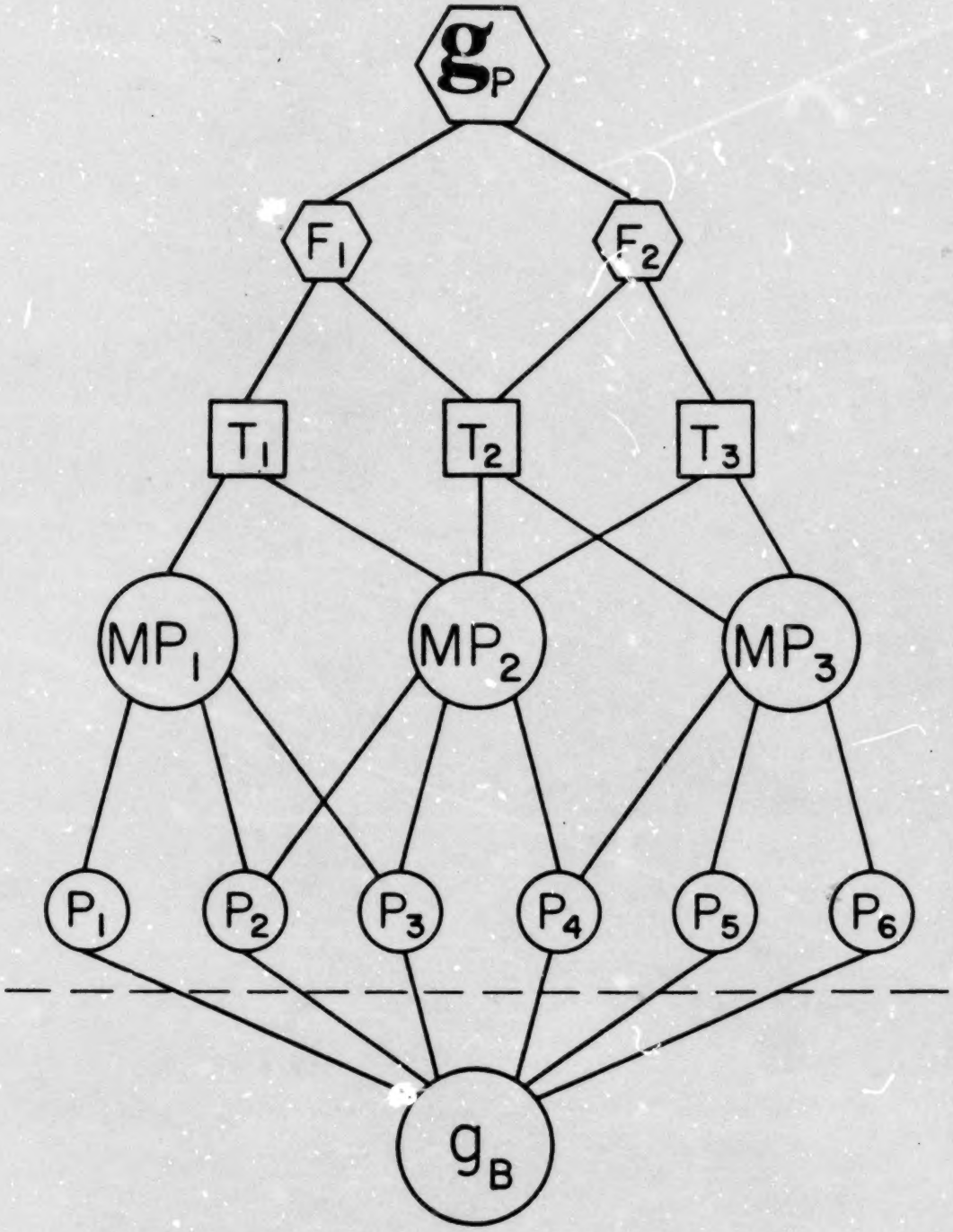

Figure 1. Simplified representation of relationships among processing and psychometric variables. See text for explanation.

physiological processes, such as cortical conductivity (Klein & Krech, 1952), synaptic errors (Hendrickson, 1982), neural oscillation (Jensen, 1982), and the like. The physiological level is represented as one general factor, g_B (B for "biological"), although, given our present state of knowledge, this level could just as well be represented as several distinct physiological processes or as correlated processes, due to their sharing one common process, i.e., g_B. The nature of this physiologic underpinning of human abilities is a major focus of Eysenck's (1982) theorizing about the findings of correlations between features of the average evoked potential and psychometric g, or g_P, which is depicted in the hexagon at the top of the hierarchy in Figure 1. All of the solid lines in the figure represent correlations.

The various elementary cognitive processes (P) are correlated through their sharing of common physiological processes. Different parts of the brain or different neural assemblies are presumably specialized for various aspects of information processing. These processes are described by terms such as stimulus apprehension, iconic memory, stimulus encoding, short-term memory (STM), rehearsal of encoded STM traces, memory scanning, retrieval of information from long-term memory (LTM), transfer, discrimination, generalization, transformation of encoded information, mapping of relations, visualization and mental rotation of figures in 2- or 3-dimensional space, and response execution. The processes (P) in this model, depicted here as being closely connected with some biological substrate, can all be measured by means of chronometric tasks, either directly or through derived scores. By subtraction of response latencies of simple tasks from those of more complex tasks, one can measure individual differences in the additional

processes involved in the more complex tasks. Various processes can also be identified by the use of partial correlations or by a factor analysis of a combination of various tasks intended to tap different processes.

Different sets of elementary processes, P, can be utilized by a given metaprocess (MP). Because metaprocesses are further removed from the biologic substrate and are probably mainly products of learning and practice, their connection to the biologic substrate is via the elementary processes which enter into the metaprocesses. Metaprocesses consist of strategies for selecting, combining, and using elementary processes, problem recognition, rule application, planning, allocation of resources, organization of information, monitoring one's own performance, and the like. Different metaprocesses are intercorrelated because they share certain elementary processes in common and also because the experiential factors which inculcate metaprocesses are correlated in the educational and cultural environment. It is probably at the level of metaprocesses that cultural differences have their primary impact.

Both processes and metaprocesses enter into performance on complex psychometric tests (T). Even a single complex test item may well depend upon a number of Ps and MPs for successful performance. Various tests are intercorrelated, moreover, not only because they share certain common Ps and MPs but also because they may share common information stored in long-term memory. Note that at each level in this hierarchy, something new is added in terms of environmental inputs. The cumulative impact of these acquired elements is at its maximum at the level of single items in psychometric tests. Item variance is largely

specificity, a technical term in factor analysis, referring to a source of variance which is peculiar to a particular item (or a particular test) and not shared in common with other variables. Specificity may arise from individuals' idiosyncratic experiences, making for unique and uncorrelated bits of information, or from complex and unique interactions among the P and MP demands and the informational content of a particular test item. In fact, all primary psychological measurements are saturated with task-specific variance. Chronometric measurements of elementary processes are no exception. Specificity, which is the bane of individual differences research, can be reduced only by using composite scores or factor scores (which are a particular weighted composite of the component scores) derived from a number of varied tasks or tests, thereby "averaging out" the specificity of the individual tasks.

The top part of the hierarchy in Figure 1, including T, F, and g_p, encompasses the realm of traditional psychometrics, including various test scores and hierarchical factors extracted by factor analysis. Here, for the sake of simplicity, are represented only two first-order factors (F and F_2) and one second-order factor, psychometric g, or g_p. The most general factor, of course, may emerge as a third-order or other higher-order factor. Each successively higher factor level excludes some source of variance. The primary factors, for example, exclude the test-specific variance, and the second-order factors exclude the variance that is peculiar to each primary factor, and so or. The most general factor, g_p, is the variance common to all the sources below it in the hierarchy.

Some homogeneous tests, such as Raven's Progressive Matrices,

contain relatively little specificity and are therefore quite good measures of g_p. Other tests, like the Wechsler scales, although containing quite heterogeneous items and subtests with considerable specificity, yield composite scores from which, in effect, the specificity is averaged out, providing a good measure of

Superficially very different tests, such as Verbal Analogies, Digit Span, and Block Designs, are intercorrelated presumably not because of common content or correlated educational experiences, but because they have a number of elementary processes and metaprocesses in common. Because the more superficial differences between tests contribute mainly to their specificities, these differences are not reflected in g_p. Hence it has been found that g factor scores are more highly correlated with chronometric measures of elementary processes than are any particular types of tests. Vernon (1983), for example, found that all of the correlations between the Wechsler Adult Intelligence Scale (WAIS) and a number of reaction time measures (from several elementary cognitive tasks) were due to the general factor of the WAIS. When the g factor was partialled out, none of the WAIS subtest scores correlated in the least with the RT measures. Thus, although g_p and P_1, P_2, etc., appear widely separated in the schematic hierarchy, they actually seem to have greater variance overlap, as shown by the correlation, than do some of the more proximal variables. This picture may also help to elucidate the otherwise surprising finding that, although g_p is derived from factor analysis of psychometric tests which bear virtually no superficial resemblance in format, content, or method of administration to the RT techniques used in elementary cognitive tasks (ECTs), g_p shows correlations almost as large with ECTs as with the psychometric tests

from which g_P is derived.

One of the crucial theoretical questions, with reference to Figure 1, regarding which there is presently little consensus, is whether more of the variance in psychometric g (g_P) is attributable to the processes (P) or to the metaprocesses (MP). The learned information content in the psychometric tests (T) can already be virtually ruled out as an important source of g variance, because tests that differ markedly in their information content, such as vocabulary and matrices, are nevertheless highly saturated with one and the same g. The multiple correlation of several simple ECTs with g_P has been so substantial in some studies as to suggest that perhaps fifty percent or more of the g_P variance is accounted for by individual differences in elementary cognitive processes (e.g., Vernon, 1983). If task specificity were further minimized in such studies, by using at least three or four different techniques for measuring each of the elementary processes that have already been shown to yield substantial correlations, it seems likely that even as much as 70 percent of the g variance would be associated with the elementary processing variables. Also, the existing studies have not taken sufficient account of the reliability of these processing measures. Proper corrections for attenuation might appreciably raise the correlations between ECTs and g_P. Split-half or other internal consistency estimates of the reliability of ECTs usually overestimate the test-retest reliability, and it is the test-retest reliability which should be used in correcting correlations for attenuation when the correlated measurements have been obtained in different test sessions, on different days, for example, or even at different times of the same day, such as before and after lunch. Some

of the ECT measurements are so highly sensitive to an individual's fluctuating physiological state from morning till night and from day to day as to have quite low test-retest reliability as compared with most psychometric tests. Theoretical interest, of course, focuses on the true-score multiple correlation between the elementary cognitive processes and g_p. One feasible goal of this research would be to determine the relative proportions of variance in g accounted for by each of a number of clearly identifiable processes and metaprocesses.

It is my conjecture that most of the present attempts at training up intelligence have their greatest observable effects, in terms of the hierarchy in Figure 1, at the level of specific psychometric tests (T_1, T_2, etc.). Training effects will fade at the higher levels of the hierarchy--the primary factors (F) and the general factor (g_p). Since a treated group will possibly show gains in the specificity of a number of tests, and since these specificities will therefore be correlated within a group composed of treated and untreated individuals, any apparent gains in the primary and general factors will be artifactual; that is, the g factor extracted from a battery of tests given to a sample of treated individuals will not be entirely the same as the g obtained in a sample of untreated individuals. The g of the treated group would be predicted to show correlations with various nonpsychometric criteria that differ from the correlations found in untreated groups. In terms of Figure 1, the chain of causality between the level of T and the lower levels of the hierarchy will have been disrupted. Treatment gains at level T and above that are not reflected in gains in the measurements at the levels of metaprocesses and elementary processes are most likely subject to fade-out within a year or two and would show little transfer

effect to "real life" achievements. This is the condition we have most often observed in programs aimed at training up intelligence.

How and to what extent training can be focused on metaprocesses and elementary processes remains to be explored, although there are already some signs of success for types of performance with inferred connections to certain metaprocesses (Detterman & Sternberg, 1982). But there is little evidence, to my knowledge, of training effects on elementary cognitive processes.

What is still most unclear is the relative amounts of variance in psychometric g that are associated with individual differences at the levels of elementary processes and metaprocesses. While it seems more plausible that the metaprocesses should carry the larger source of variance, certain recent findings make me wonder. In a number of elementary cognitive tasks so simple that individual differences can be reliably measured only in terms of reaction times or response latencies, we have found average between-group performance differences which are almost as large, in terms of standard deviation units, as the group differences in IQ itself. Nor is it at all clear that any kind of training could appreciably influence performance on elementary cognitive tasks. Practice effects on these tasks are almost negligible.

One of the most surprising findings comes from a study of academically gifted children, which I have done in collaboration with Sanford Cohn of the Johns Hopkins University and Jerry Carlson of the University of California at Riverside. A group of manifestly gifted children, succeeding in university courses in math and science at 12 to 14 years of age, was compared with a same-age group of average and bright junior high school pupils on a battery of elementary cognitive

tasks, all based on reaction times to simple stimuli. The tests are so simple that if performance were merely scored in terms of number of right and wrong responses, instead of in terms of response latencies, the true-score variance would be absolute zero. These tests have minimal intellectual content and some have none at all--such as simply removing one's index finger from a pushbutton when a light flashes on. Yet on every one of these tasks, even the simplest, with response latencies around 250 milliseconds, the gifted and nongifted groups differ significantly beyond the .001 level--differences ranging from about one to three standard deviations. They did not differ any more than that on Raven's Matrices, a high-level test of *g*. Scores from a reaction time test based on the Hick paradigm, in which the subject simply lifts his or her finger from a pushbutton when one light in a panel of anywhere from 1 to 8 light bulbs goes on, were subjected to a discriminant analysis. This analysis correctly classified 87 percent of the subjects as gifted or nongifted. The few errors in classification were pupils in the "nongifted" group. Evidently, academically gifted children differ from their more average age-mates not only at the level of academic knowledge and high-level scholastic skills which might be accounted for by certain metaprocesses. They differ also in speed and efficiency at the level of the most elementary cognitive processes. Indeed, it seems reasonable to believe that the direction of causality in individual differences goes from the elementary cognitive processes (and their physiological basis) to the relatively high-level knowledge and cognitive skills involved in successful performance on IQ tests and in academic achievement. Certainly, it is much harder to imagine how possession of the knowledge content of IQ tests and scholastic

achievement tests could possibly confer any advantage in the speed or efficiency of performing the elementary cognitive tasks.

If there is a practical implication of these findings for developing nations that want to develop the intellectual, technical, and scientific resources latent in their populations, it is this: If financial and educational resources are limited, count on selection more than on training per se for most quickly and efficiently increasing the amount of manifest talent from which the nation can benefit. Develop suitable techniques for discovering those individuals for whom the investment of limited educational resources will pay the greatest dividends. And apply these techniques far and wide in every sector of the population, regardless of class, caste, or race. The distribution of talent cuts across all such classifications. If such advice may sound elitest and does not sit well with dyed-in-the-wool egalitarians, I can only say it is the most predictably safe bet that psychology is now able to offer.

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